RESEARCH BULLETIN 723 AUGUST, 1952

Accumulation of RADIOISOTOPES in Corn Leaves

J. D. SAYRE

Ohio Agricultural Experiment Station

Wooster, Ohio

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Accumulation of Radioisotopes in Corn Leaves

J. D. SAYRE [1] [2]

INTRODUCTION

The study of mineral element physiology of the corn plant has been carried on at the Ohio Agricultural Experiment Station for many years. This study has progressed in several directions such as the seasonal accumulation of the major elements in corn plants, the accumulation of mineral elements, especially the minor elements in corn leaves, differential accumulation in inbred lines and hybrids, deficiency and toxicity symptoms in leaves, and several other subjects.

The introduction and availability of radioisotopes[3] through the Atomic Energy Commission's program at Oak Ridge, Tennessee has made possible new types of research on the movement and accumulation of many mineral elements in plants which were not possible before. By the use of radioisotopes, the movement, accumulation, and location of elements in biological material can be studied in amounts too low to be detected by any other method of analysis.

METHODS OF GROWING THE PLANTS IN GRAVEL CULTURES

The corn for the experiment reported here was grown in 3 gallon sloping bottom pots. Each pot, Figure 1, held 33 pounds, or 15,000 grams, of pure quartz gravel. A 5 gallon distilled water bottle was used as a reservoir and 15.2 liters of nutrient solution made up for each culture. This solution did not fill the bottle but left about 4 liters of air in each for possible overflow in case of a heavy rain. It required 3.3 liters of solution to flood the gravel.

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[1]Ohio Agricultural Experiment Station and Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, United States Department of Agriculture, Wooster, Ohio.

[2]Supported in part by a grant from the International Minerals and Chemical Corporation.

[3]The radioactive isotopes used in this work were obtained from the Isotopes Division of the Atomic Energy Commission, Oak Ridge, Tennessee.

The solution was forced up into the gravel culture with low pressure air from a small Crowell-type air pump. When the pump stopped the solution drained back into the reservoir by allowing the air in the solution bottle to be forced back through the pump and the by-pass valves. As the solution drained back into the reservoir, a fresh supply of air was drawn into the gravel and furnished almost perfect aeration for the root systems. The air pressure was adjusted by micro by-pass valves so that the culture was just flooded in 15 minutes. The cycles of irrigation were controlled by a time clock five times a day. The free air space in the gravel was about 3.3 liters and the gravel held about 350 ml. of solution by capillarity.

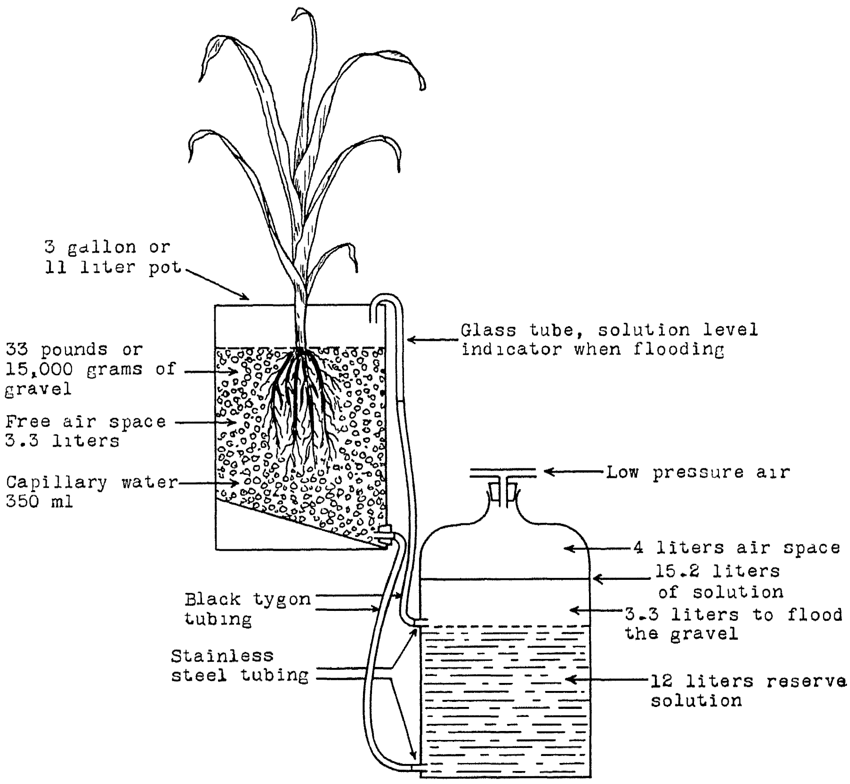

Fig. 1.—Diagram of the culture system used in growing the corn for the experiments.

TABLE 1.—Composition of solution used in the gravel cultures, summers 1950, 1951

		Optimum Solution									
	Element	Na	K	Ca	Mg	N*	N*	P	S	Cl	
		23	39	40	24	14	14	31	32	35	= M. W.
Salt	Molecularity	Parts per million in the solution									
KH_2PO_4	.000333		13					10			
KNO_3	.00177		69			25					
KCl	.000977		38							35	
$Ca(NO_3)_2$	.0025			100		70					
Na_2SO_4	.000625	29							20		
$MgSO_4$	.000825				20				26		
$(NH_4)_2SO_4$	.00017						5		6		
Total ppm		29	120	100	20	95	5	10	52	35	

*Nitrate and ammonium nitrogen.

The composition of the optimum solution used in these cultures is given in Table 1. Finely ground magnetite was used as a source of iron for the plants. No pH adjustment is possible in these cultures where this form of iron is used because the pH of the nutrient solution is maintained at approximately pH 6.1 by the vigorously growing plants themselves. The minor elements were added in a mixture, the composition of which is shown in Table 2. When the plants were very young the

TABLE 2.—Parts per million of minor element in nutrient solution. Dissolve in 16 liters of O.IN H_2SO_4

Salt	Grams	ppm*
H_3BO_3	45.80	0.5
$MnCl_2 . 4H_2O$	29.00	.5
$ZnSO_4 . 7H_2O$	3.55	.05
$CuSO_4 . 5H_2O$	1.26	.02
MoO_3	.28	.01
NH_4VO_3	.368	.01
K_2Cr_2O7	.905	.01
$NiSO_4 . 6H_2O$	.760	.01
$Co(NO_3)_2 . 6H_2O$	.790	.01
$NaWO_4 . 2H_2O$	.286	.01
TiO_2	.267	.01

*Parts per million of element only when stock solution is added to nutrient solution at the rate of 1 ml. per liter of nutrient solution.

minor elements were used at half strength or 0.5 ml. per liter of nutrient solution. The solutions were renewed completely every 3 or 4 weeks.

Although the corn was planted two weeks earlier in 1951 than in 1950 an extended cool spell of weather occurred right after planting in 1951 so the corn did not reach tasseling or silking any earlier. The addition of the isotopes and sampling of leaves occurred on almost identical dates in each of the two years.

LOG OF THE EXPERIMENTS

1950	
June 6	Corn planted, 4 seeds to culture.
June 14	Thinned to 1 and 2 plants per pot.
June 20	Optimum solution added to all the cultures.
June 27	Minor elements added to all the cultures.
July 17	Adjusted water level, checked all tubes and connections.
July 22	Changed and cleaned all solution bottles and added new optimum solutions to each.
July 25	Added radioisotopes to the cultures.
July 26	Most plants in silk.
Aug. 18	Obtained half-leaf samples of all cultures.
Sept. 6	Obtained second sample of leaf tissue.
Sept. 11	Photographed and harvested the plants, ended the experiment.
1951	
May 24	Corn planted, 4 seeds to a culture.
May 30	Cool period of weather.
June 5	Added nutrient solution to all cultures.
June 12	Thinned to 2 plants per culture.
June 25	Renewed all solutions, thinned to 1 plant.
July 23	Cleaned all bottles and changed all solutions.
July 24	Added radioactive isotopes to cultures.
Aug. 15	Sampled leaf tissue.
Sept. 2	Obtained second sample of leaf tissue.
Sept. 6	Harvested the plants and ended the experiment.

SPECIFIC ACTIVITY OF THE ISOTOPES

The radioisotopes were obtained from the Oak Ridge National Laboratories through allotment by the Atomic Energy Commission for research purposes. Small quantities of the isotopes were obtained, usually dissolved in dilute acid solution. The small amount of liquid containing the isotopes was carefully washed into a volumetric flask with distilled water.

The phosphorus was obtained as a unit of potassium acid phosphate. It consisted of 30.735 grams of KH_2PO_4 having a total activity of about 205 millicuries of phosphorus 32 on July 12, 1950. It was dissolved in water and made up to a liter in a volumetric flask. 2.26 ml. of this solution containing the 69.46 milligrams of potassium acid phosphate equal to 0.167 millicuries of phosphorus 32 were added to the culture on August 3, 1950.

The sulfur was received as 0.4 ml. of 0.09 normal sulfuric acid containing 4.46 millicuries of sulfur 35 to which no carrier had been added. It was transferred to a 250 ml. flask and made up to volume. 200 ml. of this solution containing the 2.73 millicuries of sulfur 35 were added to the 15.2 liters of nutrient solution on July 25, 1950.

The chlorine was received as 4.3 microcuries of chlorine 36 in 0.5 ml. of 1.03 normal hydrochloric acid. This was made up to 250 ml. with distilled water, and 200 ml. of the solution containing 3.45 microcuries of activity in 15 milligrams of the chloride were added to the nutrient solution on July 25, 1950.

The radioactive calcium was obtained as 10 microcuries of calcium 45 in 108 ml. of calcium chloride in weak hydrochloric acid solution. It was not diluted for use in the cultures. 80 ml. of this solution having 2.95 microcuries of activity of calcium 45 in 4.66 grams of calcium were added to the culture on July 25, 1950.

The cobalt was received as 4.0 millicuries of cobalt 60 as cobalt chloride in 4.0 ml. of 1.51 normal hydrochloric acid solution. This solution was diluted to 250 ml. in a volumetric flask with distilled water, and 140 ml. of this solution having 2.25 millicuries of activity of cobalt 60 in 2.13 milligrams of cobalt as cobalt chloride were added to the culture on July 25, 1950.

The zinc was obtained as 4.0 millicuries of zinc 65 as zinc chloride in 4.0 ml of 0.05 normal hydrochloric acid solution. This solution was made up to 250 ml. in a volumetric flask, and 125 ml. containing 2.00 millicuries of activity in 11.4 milligrams of zinc were added to the nutrient solution on July 25, 1950.

The selenium was received as 4.34 millicuries of selenium 75 as selenium chloride in 0.7 ml. of 4.98 normal hydrochloric acid solution. This solution was made up to 250 ml. in a volumetric flask, and 125 ml. containing 2.17 millicuries of activity of selenium 75 in 8.05 milligrams of selenium were used on July 25, 1950.

The silver was obtained as 4.15 millicuries of silver 110 as silver nitrate in 1.0 ml. of 0.96 normal nitric acid solution. The solution was made up to 250 ml. in a volumetric flask, and 125 ml. containing 2.07 millicuries of activity of silver 110 in 44.5 milligrams of silver were added to the culture on July 25, 1950.

The antimony was received as 2.86 millicuries of antimony 124 as antimony chloride in 132.5 ml. of 4.96 normal hydrochloric acid solution. 33 ml. of this solution was used without dilution. It contained

0.59 millicuries of activity of antimony 124 in 66 milligrams of antimony on July 24, 1951.

The cesium was received as 4.52 millicuries of cesium 134 as cesium chloride in 0.4 ml. of 0.032 normal hydrochloric acid solution. This was diluted to 250 ml. in a volumetric flask with distilled water, and 33 ml. added to the culture on July 24, 1951. It contained 0.90 millicuries of cesium 134 in 0.336 milligrams of cesium as cesium chloride.

The wolfram was obtained as 4.05 millicuries of wolfram 185 as potassium wolfrate in 6.2 ml. of 0.32 normal hydroxide. This was diluted to 250 ml. in a volumetric flask with distilled water, and 50 ml. containing 0.81 millicuries of activity of wolfram 185 in 18.4 milligrams of wolfram as the potassium wolframate in dilute hydroxide solution were added to the cultures on July 31, 1951.

The iridium was received as 3.5 millicuries of iridium 192 as iridium chloride in 10.6 ml. of 2.73 normal hydrochloric acid solution. It was made up to 250 ml. in a volumetric flask with distilled water. 50 ml. of this solution containing 0.59 millicuries of iridium 192 in 1.53 milligrams of iridium were added to the culture on July 24, 1951.

The mercury was obtained as 3.96 millicuries of mercury 203 as mercuric nitrate in 10.0 ml. of 4.5 normal nitric acid solution. This was made up to 100 ml. in a volumetric flask, and 25 ml. used in the cultures on July 24, 1951. It contained 0.74 millicuries of mercury 203 in 172.5 milligrams of mercury as nitrate in dilute nitric acid.

The thallium was received as 4.10 millicuries of thallium 204 as thallium nitrate in 2.0 ml. of 6.59 nitric acid solution. This was put in 250 ml. in a volumetric flask, and 50 ml. of the solution containing 0.82 millicuries of activity of thallium 204 in 19.3 milligrams of thallium were added on July 24, 1951.

The half-life and specific activity of the isotopes used in these experiments are shown in Table 3.

ADDITION OF THE RADIOISOTOPES

The radioisotopes were received from Oak Ridge early in the summer and were transferred to volumetric flasks. About silking time when the plants were full grown the radioisotopes were added to the solutions and the automatic irrigation system brought them in contact with the roots. Tests with a portable counter showed that many of the isotopes were accumulating in the aerial parts of the plants. Since this experiment was a preliminary test in many ways, a careful assay of the isotopes was not made, but the concentrations of the materials furnished by the Oak Ridge National Laboratories were used. It is recognized that these values may be a little high because many of the isotopes may

TABLE 3.—Half-life and specific activity of the isotopes used in the experiments

Isotope	Half-life	Specific activity mc/mg	Date assayed
Phosphorus 32	14.3 days	0.035	7–12–1950
Sulfur 35	87.1 days	carrier free	6–23–1950
Chlorine 36	4.4 x 10' years	0.00023	6–23–1950
Calcium 45	152 days	0.0000016	12–29–1949
Cobalt 60	5.2 years	1.06	7– 7–1950
Zinc 65	250 days	0.175	7– 7–1950
Selenium 75	127 days	0.27	7– 7–1950
Silver 110	270 days	0.046	7– 7–1950
Antimony 124	60 days	0.0108	7– 6–1951
Caesium 134	2.3 years	2.7	4–27–1951
Wolfram 185	73.2 days	0.044	7–27–1951
Iridium 192	70 days	0.45	7– 6–1951
Mercury 203	43.5 days	0.0057	7– 6–1951
Thallium 204	2.7 years	0.0424	4–27–1951

be absorbed by the glass containers in which they are stored. Careful observations were made of the plants and no visible injury or harmful effects of any kind were observed. Photographs of the plants used in the experiment are shown in Figures 2 and 3. When the experiment was ended, an examination of the gravel in the culture with the Geiger counter showed that large portions of several of the isotopes had been absorbed by the gravel. It was estimated that from half to ¾ of these isotopes added never left the gravel or moved into the aerial parts of the plant.

SAMPLING THE TISSUE

The cultures were carefully watched and examined frequently for accumulation of excessive radiations in the aerial parts. They were sampled twice during the experiment. This was done by carefully removing the tissue on one side of the midrib of the leaf without injuring the rest of the leaf. The green leaf tissue was cut into short sections and placed between blotting paper in a press where they remained until dry. The first samples were obtained on August 18, and the second one on September 8, 1950. In 1951 the samples were obtained on August 14 and September 2. The dried sections of leaf tissue were properly labeled and fastened lightly with clear cement to a sheet of paper on which the data on the sample was recorded.

No further preparation or treatment of the samples was necessary except to select the smoothest and most uniform samples for autoradiographs.

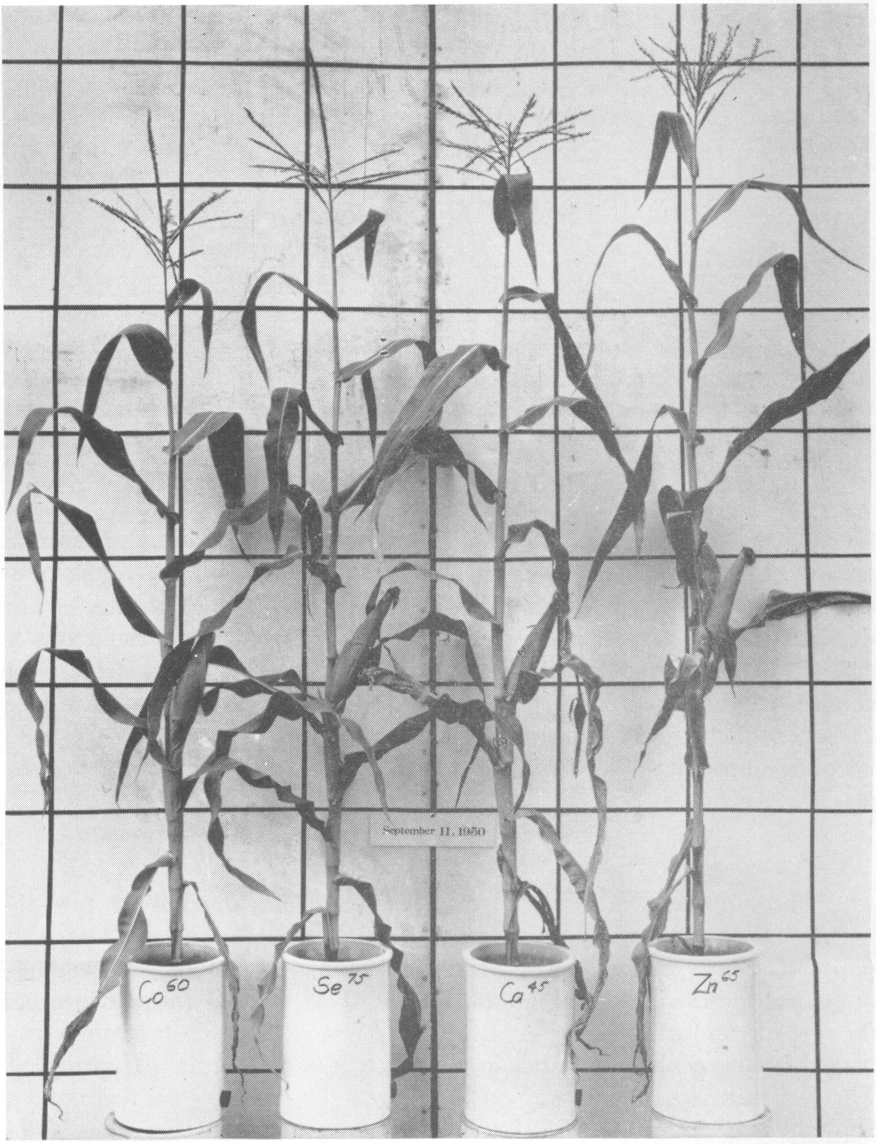

Fig. 2.—Photograph of some of the plants used in the experiments in the summer of 1950.

MAKING THE AUTORADIOGRAPHS

The autoradiographs were made on Type K Industrial X-ray film. The time required to expose the different autoradiographs varied from a few hours to many days. The sections of leaf tissue were arranged in order from base to tip with margins orientated on the same side and fastened to the sheet of paper containing the other necessary data for the sample. They were put in a metal 8 × 10 inch X-ray cassette and a sheet of Type K film placed on top of them and the cover closed carefully and tightly. The filled cassette was set away with a label stating when it should be developed. It was possible to have a number of autoradiographs being made at one time by this technique.

When ready to develop the film, the developer was adjusted to 68° F. and the film developed for 4¼ minutes with agitation and frequent turning of the film since they are coated on both surfaces. The films were fastened in metal film holders, washed briefly in water, and fixed for 20 minutes in hypo. After clearing they were washed 30 minutes in running water and dried.

Preliminary counts with a Geiger counter of a square centimeter of leaf tissue of each sample gave a starting point for the exposure. It was found that a good image could be obtained from a sample where a total

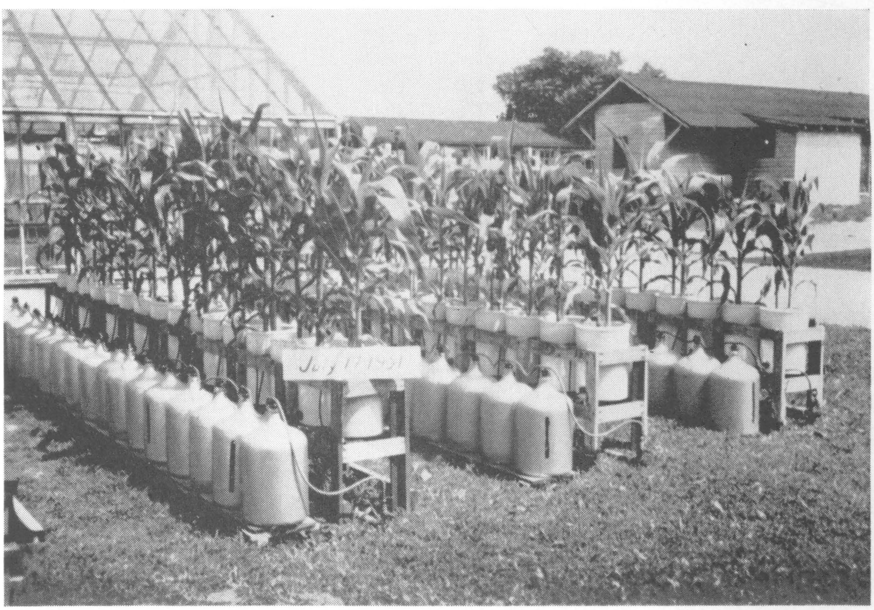

Fig. 3.—Photograph of the gravel cultures used for radioisotopes during the summer of 1951.

count of 200,000 radiations per square centimeter were obtained from the leaf tissue by a Geiger counter. The sample geometry was about 10%, thus, the film received 2,000,000 radiations per square centimeter. This was rather a crude approximation of the total count because the energy of the radiations varied from 0.169 Mev to 1.72 Mev and the counter window was not very close to the sample. After the first exposure of any specimen was complete, it was often possible to judge a better exposure for the sample, and most of the autoradiographs were greatly improved by a second or even third exposure. Several months were required to make satisfactory records from all the specimens.

At the beginning of the work, check exposures using dried corn leaves with no radioisotopes in them were made in the same X-ray cassette. But exposures of 60 days failed to show any image of the leaf structure at all from the contact with the film. Later square centimeter discs of leaf tissue without radioisotopes in them were included with each exposure. These never showed any image. Consequently, no checks were attempted during the latter part of the work. It was concluded that normal dried corn leaves had no affect on the emulsion under the light pressure in the cassettes up to 60 days at least. Thus, an image, when radioisotopes were used, was produced by the radiations from the isotope itself.

RESULTS OF THE EXPERIMENTS

The result of the tests conducted with the radioisotopes showed some striking differences in the location, accumulation, and distribution of the various ions in the leaves.

The autoradiograph of phosphorus 32, Figure 4, showed that it accumulated about equally throughout the blade with no marked difference between margin and midrib and tip or base of the leaf or between the vein tissue.

Sulfur 35, Figure 5, accumulated about equally between the primary veins of the leaf. The veins were lower in concentration than the tissue between them. There was no difference in concentration from base to tip of the leaf and no difference from margin to midrib of the blade.

The autoradiograph, Figure 6, of chlorine 36 shows that the isotope accumulated in the margin of the blade, increasing in amount from the base to the tip of the leaf. It also showed an accumulation along the midrib but in the opposite direction, or decreasing from base to tip. The chlorine accumulated slightly in and around the veins of the blade, but there was no difference in amounts from the base to tip of the blade except as noted at the margins or near the midrib.

The accumulation of calcium 45 in the corn leaf is shown in Figure 7. This autoradiograph shows much more detail in the leaf structure than the others. The primary veins are well outlined in the autoradiograph and the secondary veins are all shown where perfect contact was made between the film and the tissue. The primary veins are lighter than the mesophyll showing lower accumulation, while the secondary veins are darker. The accumulation of the calcium 45 was uniform over the area of the leaf.

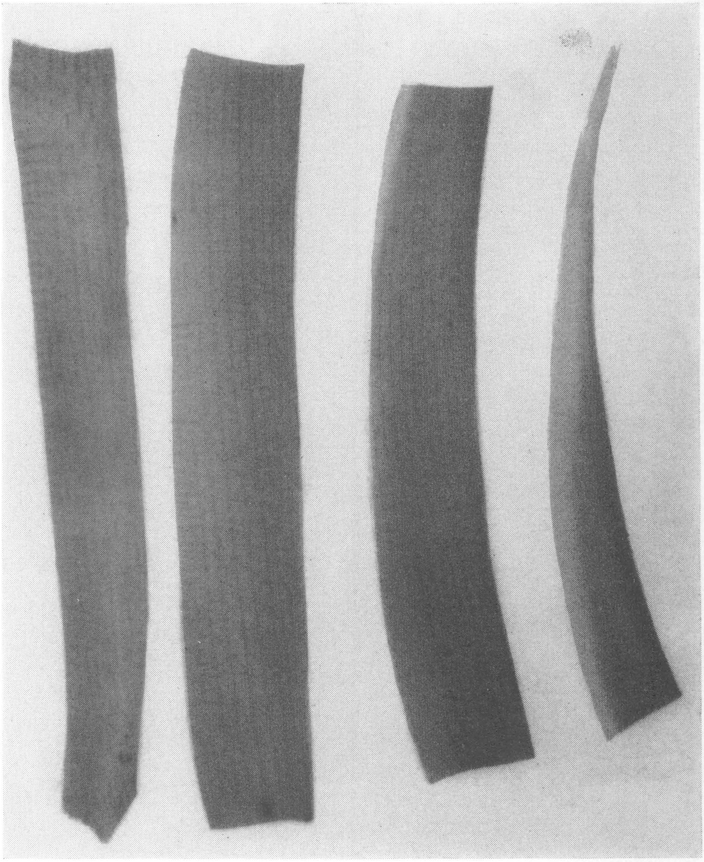

Fig. 4.—Autoradiograph of a corn leaf containing phosphorus 32. The radioactive phosphorus was distributed about equally in the leaf blade. The veins show more radioactive phosphorus than the areas between them. The leaf tissue was sampled August 18, 1950. The autoradiograph was printed October 5, 1950, exposure time 17 days.

The autoradiograph shown in Figure 8 was made from the leaf which accumulated the cobalt 60. This shows that the cobalt accumulated in very great concentrations at the margin of the leaf and increased greatly from base to tip. There was some accumulation around the veins of the leaf and a slightly greater amount toward the upper part of the blade than toward the base.

Figure 9 shows the accumulation of zinc 65 in the corn leaf. It accumulated around the primary veins of the blade but there was no difference in accumulation from base to tip or from margin to midrib.

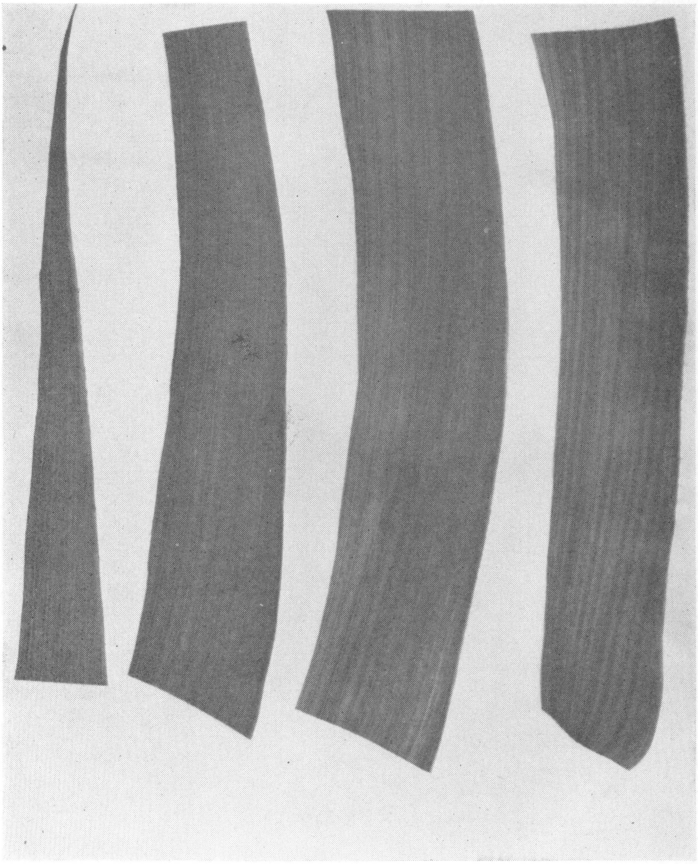

Fig. 5.—Autoradiograph of a corn leaf containing sulfur 35. The radioactive sulfur was found in about equal amounts in all parts of the leaf blade. The leaf samples were obtained August 18, 1950 from the 7th leaf down from the tassel. The autoradiograph was printed January 23, 1950, exposure time 4 days.

The selenium 75 autoradiograph is shown in Figure 10. Selenium 75 accumulated around and in the primary veins of the blade. There was no difference in distribution from margin to midrib and only a slight decrease in amount from base to tip of the blade.

The autoradiograph shown in Figure 11 was obtained from the leaves of the plant which accumulated silver 110. The silver ion had

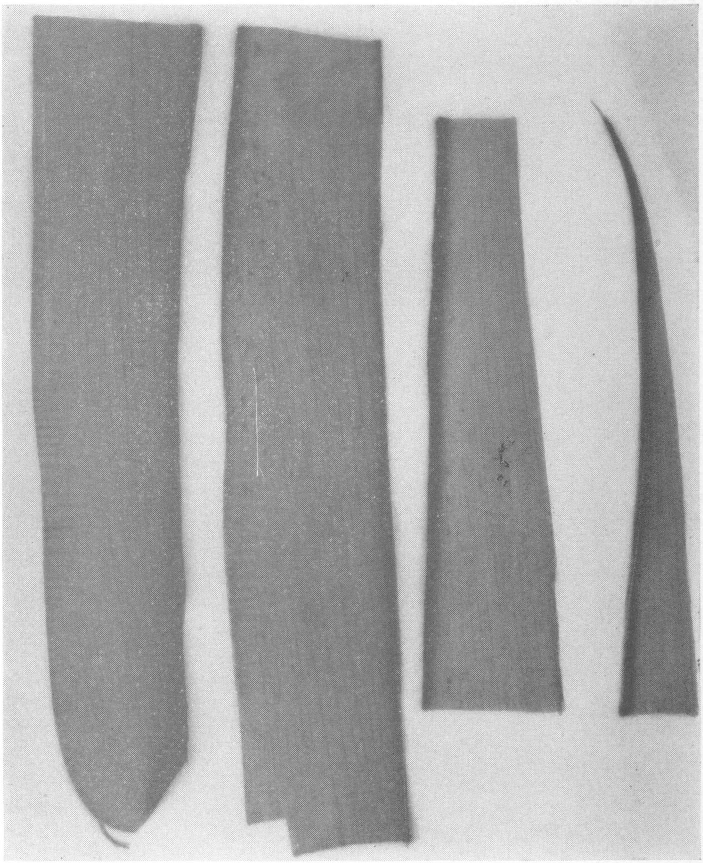

Fig. 6.—Autoradiograph of a corn leaf containing chlorine 36. The radioactive chlorine was not equally distributed in the leaf blade. It accumulated in greater amounts along the margin of the leaf and inward toward the tip. There was some accumulation near the midrib in the lower part of the leaf. The leaf samples were obtained August 18, 1950 from the 7th leaf on the plant down from the tassel, or the ear leaf. The autoradiograph was made December 18, 1950 to February 20, 1951, exposure time 64 days.

accumulated in a pattern very similar to cobalt. There was a slight accumulation in and around the primary veins and a very strong accumulation in the margins of the leaf increasing many fold from base to tip. The blade showed a slight increase in the amount of silver accumulated from base to tip.

The autoradiograph of antimony 124 shown in Figure 12 indicated that the antimony had accumulated along the margins of the leaf in

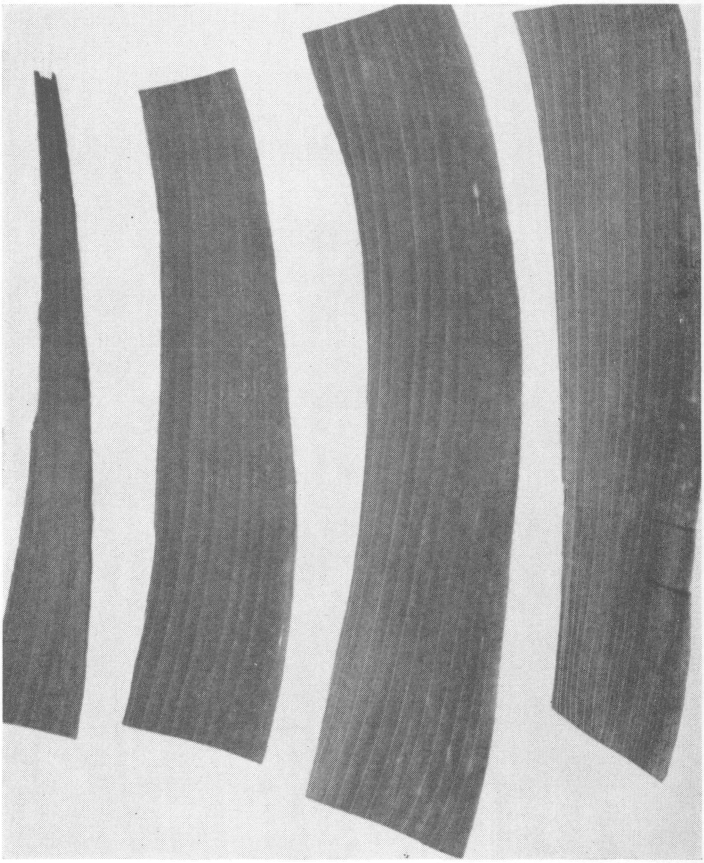

Fig. 7.—Autoradiograph of a corn leaf containing calcium 45. The radioactive calcium was uniformly distributed throughout the leaf blade. The leaf samples were obtained August 18, 1950 from the 7th leaf down from the tassel, or the ear leaf. The autoradiograph was printed November 15, 1951, exposure time 3.7 days.

much greater amounts than in the rest of the blade. There was no increase in accumulation from the base to tip either in the margin or in the blade.

Cesium 134, shown in Figure 13, showed an accumulation approximately uniform across the leaf blade. There was more cesium in the veins than in the area between them and a measurable decrease in amount from base to tip of the leaf.

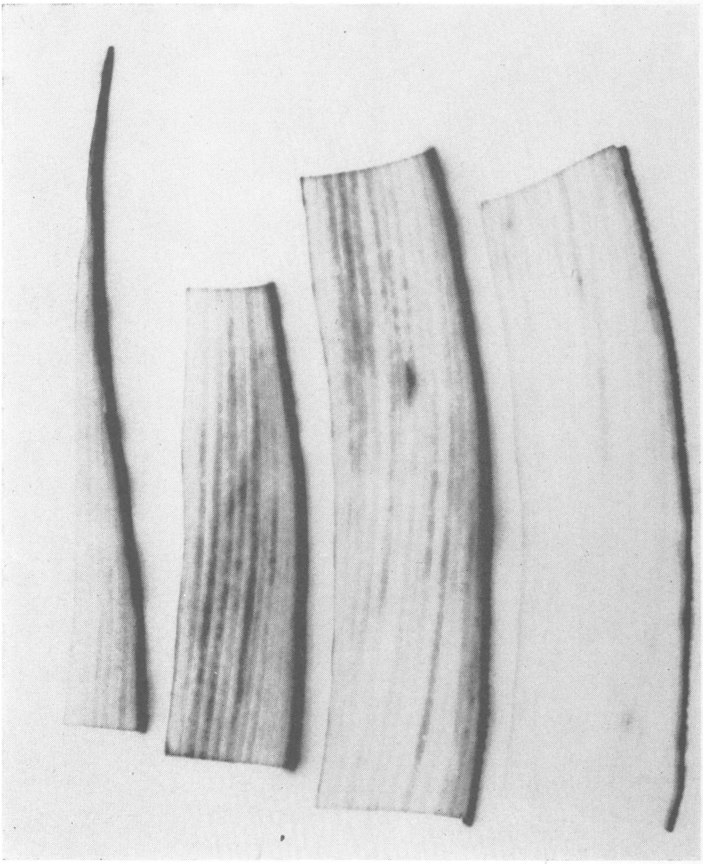

Fig. 8.—Autoradiograph of a corn leaf containing cobalt 60. The radioactive cobalt accumulated in large quantities along the margins of the leaf blade. There was a smaller amount throughout the whole blade, principally around the veins. The leaf samples were obtained August 18, 1950 from the 7th leaf down from the tassel, or the ear leaf. The autoradiograph was made November 7, 1950, exposure time 8 days.

The autoradiograph of wolfram 185, Figure 14, indicated about an equal accumulation in all parts of the leaf blade, with hardly any difference between the primary and secondary veins. There was slightly less accumulation toward the base of the leaf than toward the tip.

Iridium 192, Figure 15, showed a marginal accumulation but no great difference from base to tip along the margin. The center of the blade had a uniform amount of the iridium throughout.

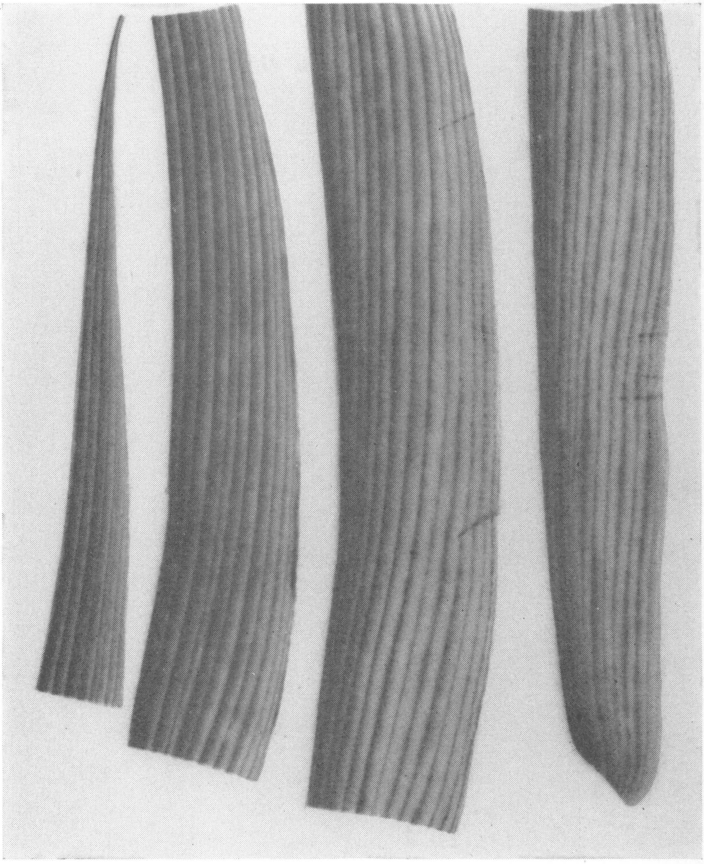

Fig. 9.—Autoradiograph of a corn leaf containing zinc 65. The radioactive zinc accumulated principally in and around the primary veins of the leaf blade. It was uniform over all parts of the leaf blade. The leaf samples were obtained on August 18, 1950 from the 7th leaf down from the tassel. The autoradiograph was made December 28, 1950 to January 5, 1951, exposure time 8 days.

The autoradiograph of mercury 203, Figure 16, indicated a high marginal accumulation of the element. It increased in amount from the base to the tip and the vein areas showed a slightly higher amount than the areas between them. The center of the blade increased in amount from base to tip.

The autoradiograph of thallium 204, shown in Figure 17, was different from any of the others. There was a high accumulation in and

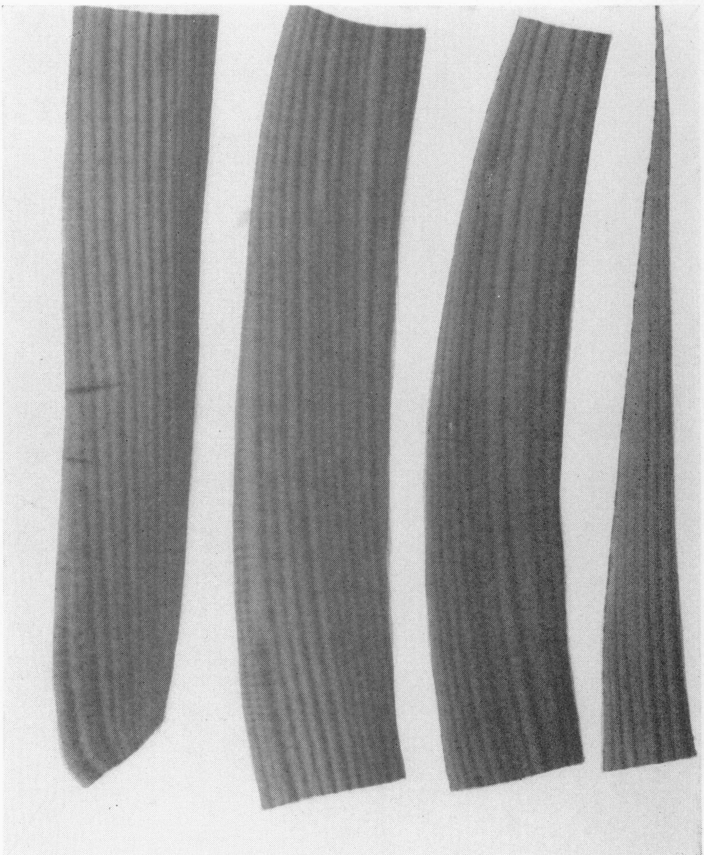

Fig. 10.—Autoradiograph of a corn leaf containing selenium 75. The accumulation of radioactive selenium was very similar to that of zinc 65. It accumulated around the primary veins of the leaf blade. The leaf tissue samples were obtained on August 18, 1950 from the 7th leaf down from the tassel, or the ear leaf. The autoradiograph was made April 13, 1951, exposure time 10 days.

around the veins but no marginal concentration at all. It appears to have accumulated only in and along certain veins of the leaf and to have diffused outward from them. The amount of thallium decreased greatly toward the tip of the leaf so it disappeared entirely from the tip section.

Three other radioisotopes were used in the work. They were scandium 46, chromium 51, and nickel 63. They were used in the same ways as all the other isotopes and under the same conditions.

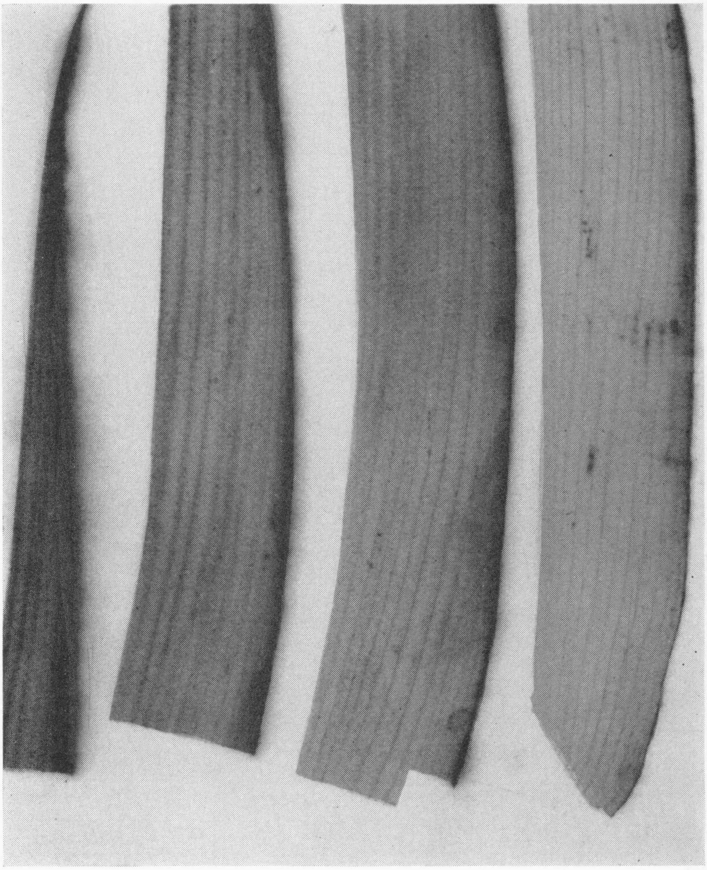

Fig. 11.—Autoradiograph of a corn leaf containing silver 110. The radioactive silver accumulated at the margins of the leaf blade. There was some throughout the blade and around the veins. The leaf samples were obtained September 8, 1950 from the 7th leaf on the plant down from the tassel. The autoradiograph was made December 28, 1950 to January 19, 1951, exposure time 21 days.

But repeated attempts to find the radioactive ion in the leaf tissue by means of the autoradiographs failed. Exposures of up to 60 days did not produce satisfactory exposures so the distribution of the element could be studied. The results of these tests were left out on this manuscript for this reason.

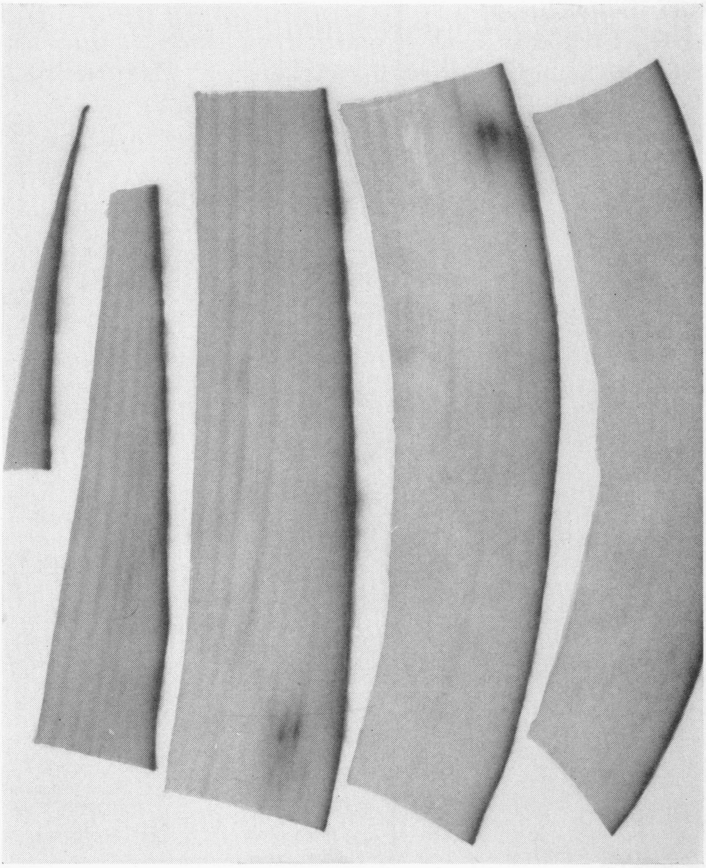

Fig. 12.—Autoradiograph of a corn leaf containing antimony 124. The radioactive antimony accumulated in very high concentrations along the margins of the leaf blade. A small amount was found in all the leaf tissue. The leaf samples were obtained August 14, 1951 from the 7th leaf on the plant down from the tassel. The autoradiograph was printed September 21, 1951, exposure time 15 days.

DISCUSSION OF RESULTS

Autoradiographs of phosphorus 32 in corn leaves have been made for several years, but they were not very satisfactory because they were not sharp or clear. There was nothing very striking in the results. It was concluded that phosphorus 32 is taken up very readily and moves to all parts of the plant.

The work reported here is much more extensive and has shown more about the autoradiographs and explains why phosphorus 32 did not

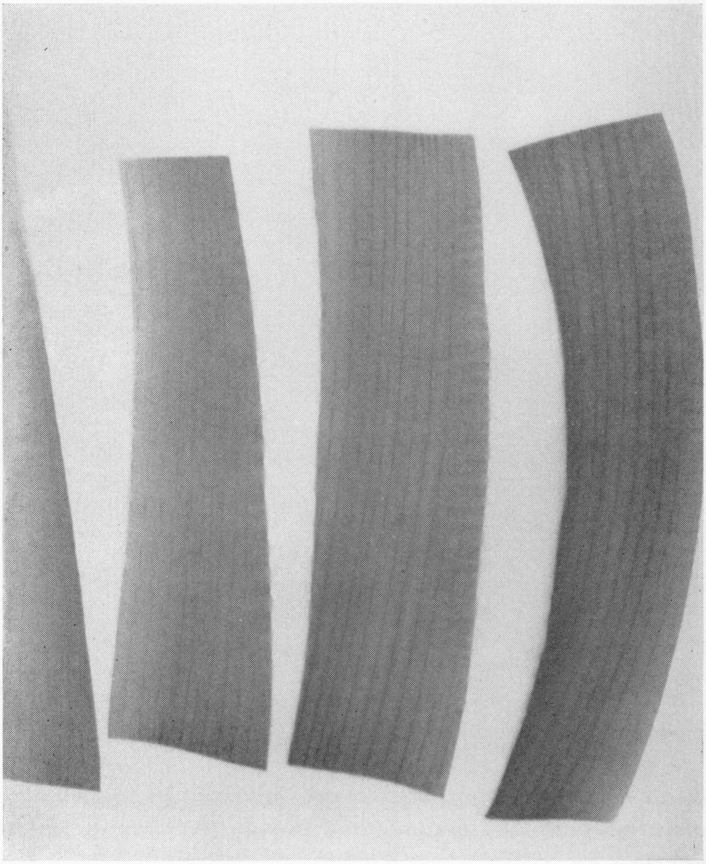

Fig. 13.—Autoradiograph of a corn leaf containing cesium 134. The radioactice cesium accumulated uniformly throughout the leaf blade. The leaf samples were obtained August 15, 1951 from the ear leaf which was the 7th leaf down from the tassel. The autoradiograph was made October, 1951, exposure time 24 hours.

produce good results. The autoradiographs shown in this publication were all obtained from dried, pressed corn leaves. The double emulsion coated X-ray film was put in direct contact with the dried section of leaves in a metal X-ray cassette and the firm pressure from the springs held them in close contact. The leaves containing the radio-active ions were about 170 microns thick. The geometry of this arrangement would be almost perfect so that all the radiation (50% geometry) would be effective in producing the image on the film.

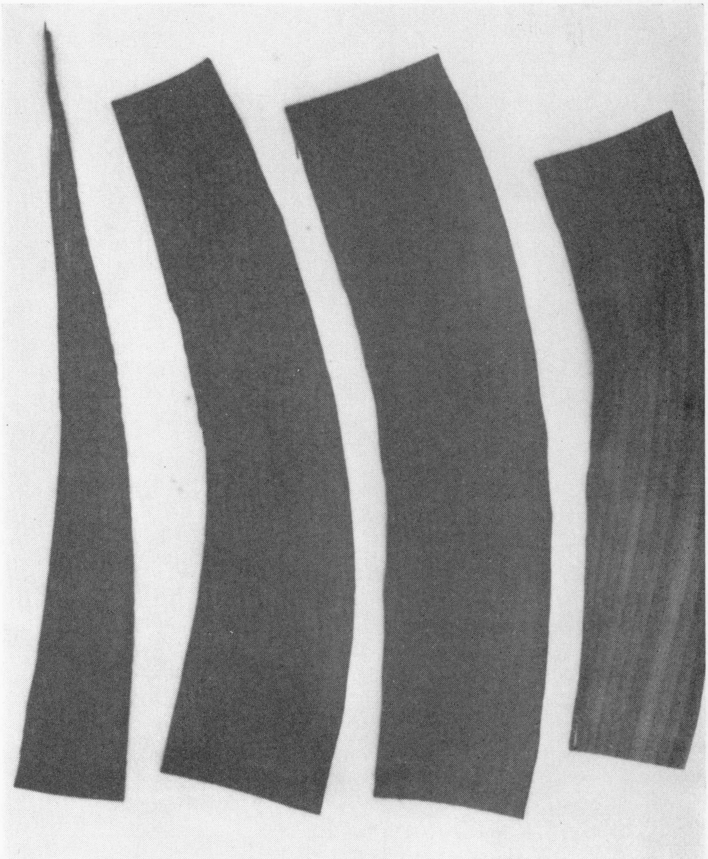

Fig. 14.—Autoradiograph of a corn leaf containing wolfram 185. The radioactive wolfram accumulated uniformly throughout the leaf blade. The leaf tissue was sampled August 21, 1951 from the 7th leaf down from the tassel on the plant. The autoradiograph was printed October 7 to October 17, 1951, exposure time 10 days.

The data in Table 4 summarize the energy and kind of radiation produced by the isotopes. These data show a wide range of energy values for both γ and β radiation. Those elements that have low energy values such as sulfur and calcium produced the clearest and sharpest autoradiographs. A careful examination of the calcium 45 autoradiograph, the mercury 203, or wolfram 185, all of which were produced by low energy radiation in contrast to those produced by phos-

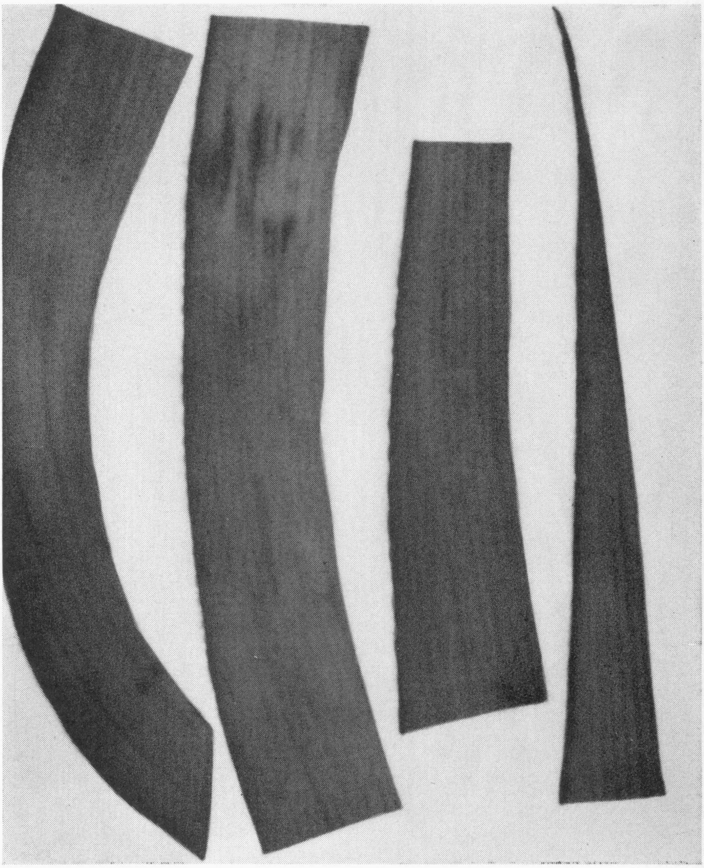

Fig. 15.—Autoradiograph of a corn leaf containing iridium 192. The radioactive iridium accumulated equally throughout the leaf blade, but with a measurably larger amount at the margins of the blade. The leaf samples were obtained August 15, 1951 from the 7th leaf on the plant down from the tassel. The autoradiograph was made August 19, 1951, exposure time 2 days.

TABLE 4.—Energy values of the radiations of the isotopes used in the experiment, and the decay product

Element	Radio active isotope	Energy of radiations in MEV				Decay product	
		β negative	β positive	γ	K capture	Element	stable isotope
Phosphorus	32	1.712				Sulfur	32
Sulfur	35	.167				Chlorine	35
Chlorine	36	.72				Argon	36
Calcium	45	.254				Scandium	45
Cobalt	60	.31		1.17 1.33		Nickel	60
Zinc	65		.32	1.12	Cu K X-rays	Copper	65
Selenium	75			Several γ's 0.076 to 0.405	As K X-rays	Arsenic	75
Silver	110	5 β's .087 to 2.86		10 γ's .656 to 1.516		Cadmium	110
Antimony	124	5 β's 0.5 to 2.37		7 γ's 0.121 to 2.3		Tellurium	124
Cesium	134	2 β's .090 and .658		4 γ's .568 to 1.35		Barium	134
Wolfram	185	.43		.134		Rhenium	185
Iridium	192	.67		Several γ's .137 to .317		Platinum	192
Mercury	203	.21		.28		Thallium	203
Thallium	204	.78				Lead	204

phorus 32, cobalt 60, silver 110, or antimony 124 will show the sharpness of the autoradiographs.

The poor autoradiographs produced by phosphorus 32 are due to the high energy of the β particles released in transmutation to sulfur 32. Phosphorus 32 is used extensively in biological work, but it does not produce sharp clear autoradiographs in comparison with sulfur 35 or calcium 45. It is obvious that the best autoradiographs are produced by

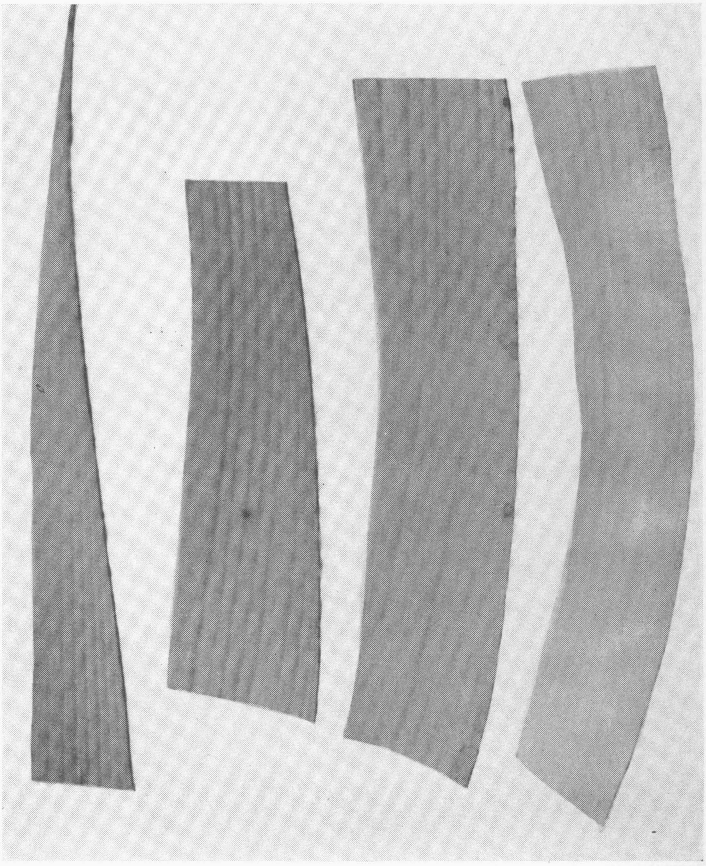

Fig. 16.—Autoradiograph of a corn leaf containing mercury 203. The radioactive mercury accumulated at the margins of the leaf blade, and also slightly throughout the whole leaf blade. The leaf samples were obtained August 14, 1951 from the 7th leaf down on the plant from the tassel. The autoradiograph was made August 26, 1951, exposure time 25 days.

low energy radiation while the best results from counting techniques are usually obtained from high energy radiations unless internal counters are available.

There may be some relation between the location or accumulation of an isotope in the leaf blade and the thickness of the tissue. A tracing was made of the leaf sections containing cobalt 60 and an outline draw-

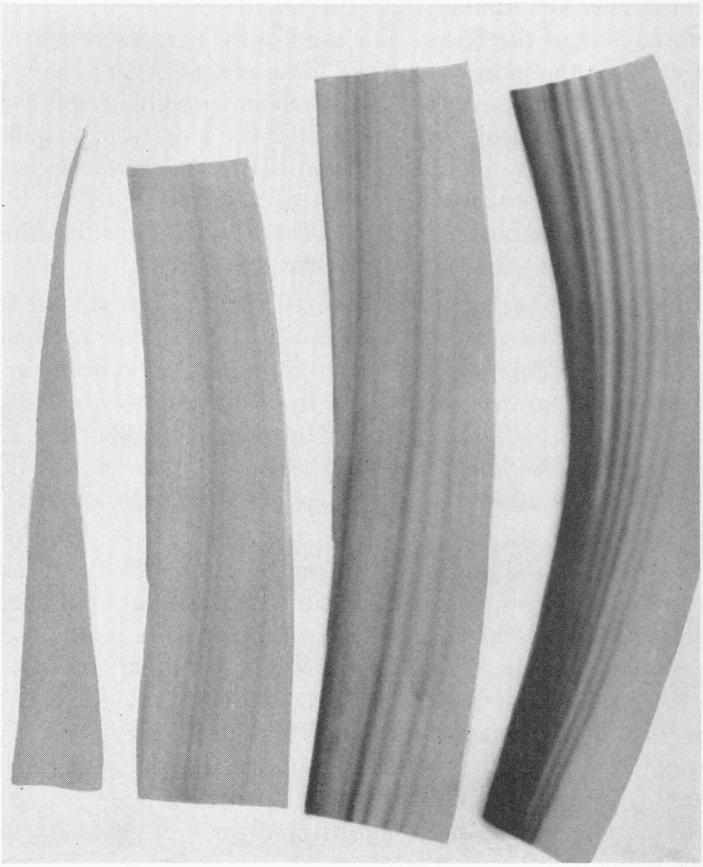

Fig. 17.—Autoradiograph of a corn leaf containing thallium 204. The radioactive thallium showed a very unequal or ununiform distribution. It appeared to follow some of the veins, but did not extend out to the tip of the blade. The leaf samples were obtained August 15, 1951 from the 7th leaf down from the tassel on the plant. The autoradiograph was made September 21, 1951, exposure time 21 days.

ing of the leaf made. This diagram is shown in Figure 18 and the thickness of the tissue in a number of places on the sections are shown in microns. The measures were made with a thickness gauge after the leaf had been pressed and dried, so they show the thickness when the autoradiographs were made. The average mass over the whole leaf area was about 6 mg/cm^2.

The margins are thinner than the tissue near the midrib, and the tips are thinner than the base. But there is no significant difference in thickness between the margins and the tissue immediately adjacent to the margins. In some instances the density of the autoradiograph is greatest in the thin parts of the leaf, but in others it is just the opposite. Obviously there are regions where certain isotopes accumulate independent of the mass of the leaf tissue.

Another very important result of the work is the differential accumulation of the various isotopes in the corn leaf.

All plants were normal and about equal in size when the isotopes were introduced. The plant with sulfur 35 had a thinner stem than the other. No visible injury such as wilting or chlorosis occurred in any of the cultures. Leaf samples were taken from the plants three weeks after adding the isotopes. This was done by carefully taking the half-leaf from one side of the midrib without injuring the rest of the leaf. Another sample was taken about three weeks later from another leaf on the plant.

All isotopes entered the root systems and moved up through the stems and into the leaves. Cobalt 60, silver 110, antimony 124, mercury 203, iridium 192, and chlorine 36 moved out into the margins and tips of the leaves and accumulated there. All of the other isotopes became more or less equally distributed throughout the blade. This fact indicates that the tips and margins of the leaves probably have a different physiological reaction than the rest of the blade. It is not surprising that some of the isotopes accumulated at the nodes or in the veins because those tissues have been known for some time to accumulate certain elements. But so far as the author is aware, the tip and marginal accumulation has never been reported before.

When deficiency symptoms of potassium or phosphorus are produced in corn, a discoloration or dying of the leaf tissue at the tips and margins of the blade results. This dying progresses downward along the margins from the tip and inward from the margins toward the midrib. Many of the elements which produce toxicity symptoms follow this same pattern. Continued work on the relation of marginal accumulation to deficiencies and toxicities in plants is being planned.

During the last half of the summer of 1951 a series of leaf samples of corn from a good field were obtained each week. They were dissected

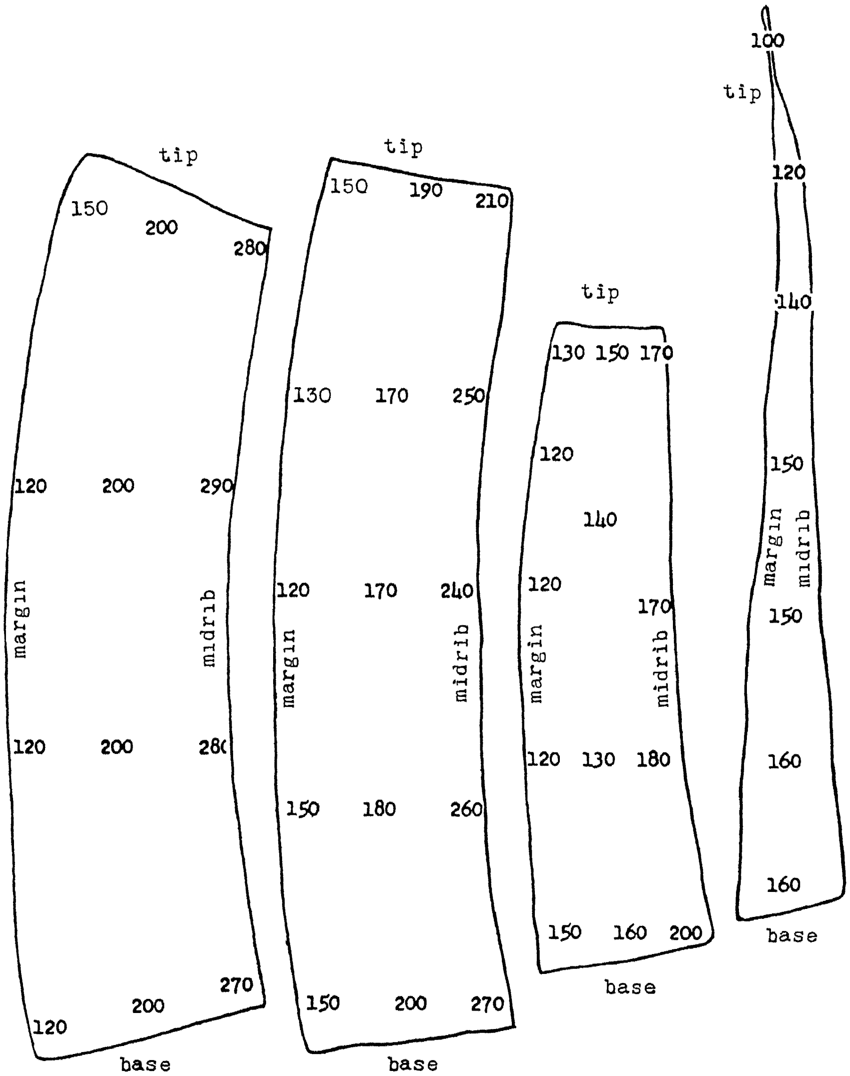

Fig. 18.—Outline drawing of one-half of a corn leaf, cut into sections, showing the range in thickness of the tissue. All values are in microns and were measured with thickness gauge on the dried pressed blade.

into margins and blades by cutting off about 3/16 of an inch of the margin. These samples were dried, ground, and analyzed on the spectrograph. The results of this examination showed a very high accumulation of boron, silica, and manganese in the margins of the leaf. Phosphorus, aluminum, copper, calcium, and iron were no different in concentration in the two samples of tissue. Potassium was slightly lower in the blade than in the margin. These results agree with the autoradiographic determination of calcium 45 and phosphorus 32 in similar tissue.

CONCLUSIONS

The best autographs of corn leaves were obtained with isotopes of low energy radiations.

The isotopes showed marked differential accumulation in the blades of the leaf. Cobalt 60, silver 110, antimony 124, mercury 203, iridium 192, and chlorine 36 showed marginal and tip accumulation. The other isotopes, phosphorus 32, sulfur 35, calcium 45, zinc 65, selenium 75, cesium 134, wolfram 185, and thallium 204, were about equally distributed throughout the blade of the leaf. There is no apparent explanation at present why this differential marginal accumulation has occurred.

ACKNOWLEDGMENTS

Most of the nuclear data on the radioisotopes used in this work were taken from the Circular of the National Bureau of Standards No. 499 issued September 1, 1950.

Dr. M. L. Pool, Professor of Physics, The Ohio State University, aided greatly in all this work by suggestions and instructions in the fundamentals of nuclear science over the years that the author has been associated with him.

Part of the cost of this publication was borne, through research grants, by the International Minerals and Chemical Corporation.

Many of the autoradiographs were developed by G. H. Glade, laboratory technician, in the Department of Agronomy, The Ohio Agricultural Experiment Station.